11p

N63 17226

Code 1

NASA CR-50,065

Technical Memorandum No. 33-111

Preliminary Results from Mariner-II Solar Plasma Experiment

Marcia Neugebauer

Conway W. Snyder

jpl

JET PROPULSION LABORATORY

CALIFORNIA INSTITUTE OF TECHNOLOGY

PASADENA, CALIFORNIA

November 15, 1962

OTS PRICE

XEROX $

MICROFILM $

Code 1

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
CONTRACT NO. NAS 7-100

Technical Memorandum No. 33-111

Preliminary Results from Mariner-II *Solar Plasma Experiment*

Marcia Neugebauer
Conway W. Snyder

Robert J. Mackin, Jr.

Robert J. Mackin, Jr., Chief
Physics Section

JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA, CALIFORNIA

November 15, 1962

CONTENTS

TABLES

FIGURES

ABSTRACT

17226

This Memorandum presents a preliminary summary of the data received from the *Mariner-II* solar plasma experiment for the period August 29 through October 31, 1962. During this period, there was always a measurably large plasma flow from the direction of the Sun. The velocity of this ion motion was generally in the range 400 to 700 km/sec. Time variations, plasma density, and ion temperature are also discussed.

I. GENERAL RESULTS

Descriptions of the *Mariner-II* electrostatic spectrometer for measurement of the solar plasma have been given elsewhere (Ref. 1 and 2). The experiment consists of a single electrostatic spectrometer which always points within less than ½ deg of the center of the Sun. For a given voltage across the deflection plates, charged particles within a certain range of kinetic energy per unit charge, E/Q, and with near normal incidence, are allowed through to the charge collector; the current to this collector is measured for each of 10 deflection voltages. After a current measurement with a zero deflection voltage and an electrometer calibration measurement, the 3.696 min cycle of 12 measurements is repeated. The spectrometer angular and E/Q resolutions are approximately ± 10 deg and $\pm 12\%$, respectively (widths at zero height). The resolution of the current measurement is one tenth of a decade, and the area of the spectrometer entrance is 5 cm^2.

Data were received from the interplanetary experiments on *Mariner-II* almost continuously from August 29 through October 31, 1962. In this period, approximately 23,550 plasma spectra were received from the spacecraft of which approximately 20,200 have already been made available for analysis.

One of the principal results discovered by the *Mariner* plasma experiment is that there was always a measurably large plasma flow from the direction of the Sun. The data from this experiment are summarized in Fig. 1 which contains eight plots of the logarithm of the collected current vs. time—one for each value of E/Q between 516 and 8224 v. Each bar represents the total spread in measured current for the time interval of 1 frame-count cycle = 256 measurement cycles = 15.77 hr.

The lines marked 130 and 140 correspond to approximately 10^{-11} and 10^{-12} amp, respectively, so that the vertical distance between these lines is equivalent to one decade of collected current. The base line corresponds to a current of approximately 10^{-13} amp. Currents below about 3×10^{-13} amp are too small to charge the electrometer capacitance completely and must be measured by calculation of accumulated charge. This latter method of current measurement, although less accurate than the direct measurement method used at higher currents, allows estimates to be made of currents down to about 10^{-14} amp. Only for one period of about 20 min was the plasma flux so low that this accumulated charge method of current measurement was required for all values of E/Q. The largest current observed during the 63 day period was about 4×10^{-10} amp. Measurements were also made at values of $E/Q = 231$ and 346 v; however, the currents in these ranges of E/Q are not plotted because they were always below 10^{-13} amp.

From Fig. 1 it can be seen that there was almost always a plasma flux at values of $E/Q = 1664$ and 2475 v (corresponding to particle velocities of 563 and 690 km/sec). Only on occasion during this period did E/Q become as low as 516 v (314 km/sec) or as high as 8224 v (1250 km/sec).

Table 1 is a summary of the fraction of time the peak of the measured spectrum fell in each of the windows of E/Q.

Table 1. Distribution of E/Q

E/Q	percent of time measured current in this E/Q was the maximum	percent of time measured current in two adjacent channels of E/Q was approximately equal
516 volts	0.0	0.2
751	18.3	2.0
1124	22.5	2.2
1664	30.5	4.0
2476	19.9	0.1
3688	0.3	
TOTAL:	91.5	+ 8.5 = 100%

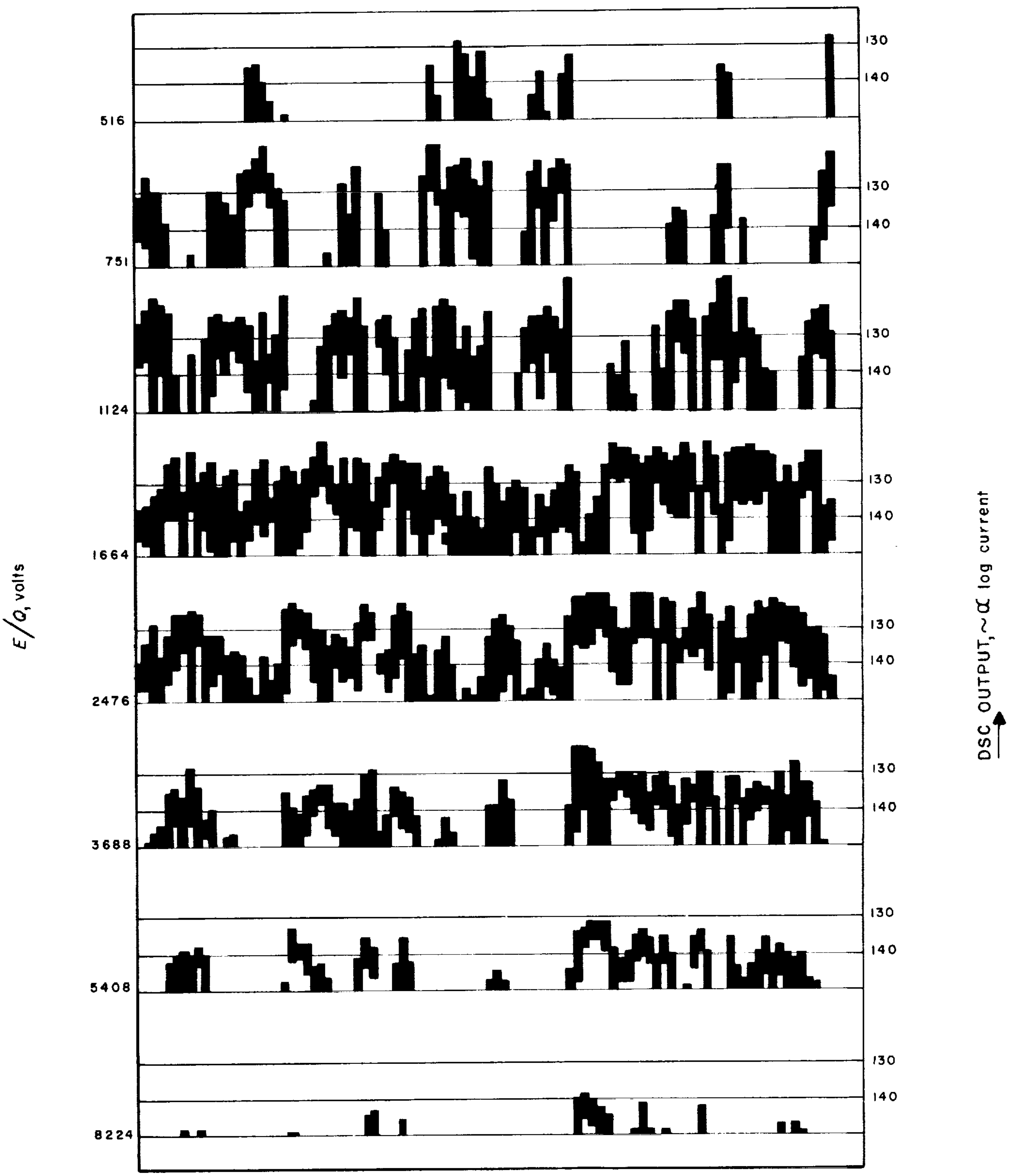

Fig. 1. Summary of solar plasma data, August 20 through October 31, 1962

II. GEOMAGNETIC STORM

There were six geomagnetic storms during the period August 29 through October 18. Figure 2 shows the plasma flux for the period of the geomagnetic storm which started at 2025 UT, October 7. One could see a sudden increase in plasma flux and energy at about 1547 UT, October 7, when the spacecraft was 8.55×10^6 km closer to the Sun than was the Earth. If it is assumed that this plasma front was advancing with spherical symmetry and constant velocity from the center of the Sun (at least for the region of space containing the spacecraft and the Earth), then the velocity of the front was 504 km/sec. This velocity corresponds fairly well to the measured plasma velocity spectrum in which more current was measured at 464 km/sec than at 379 or 563 km/sec.

The discontinuity, or plasma front, passed the spacecraft so quickly that the instrument with its 3.7 min time resolution could not resolve its structure, which must therefore be less than 112,000 km thick. The *Mariner* magnetometer data for this period could be interpreted as showing a front thickness of the order of 50,000 km.

Another interesting feature of the plasma spectrum during this period, which Table 2 and Fig. 2 show, is that the energy of the ions in the plasma kept increasing for approximately one day after the passage of the initial front. Similar behavior was exhibited by the plasma spectra associated with most of the other geomagnetic storms.

Table 2. Increase of plasma energy with time for October 7 geomagnetic storm

Time	Value of E/Q for which the largest current is observed
Before 1547, Oct. 7	751 v
1547 to 2130, Oct. 7	1124 v
2130, Oct. 7 to 0015, Oct. 8	1124 and 1664 v approximately equal
0015 to 0230, Oct. 8	1664 v
0230 to 0500, Oct. 8	1664 and 2476 v approximately equal
0500 to 1545, Oct. 8	2476 v
1545, Oct. 8 to 0330, Oct. 9	Alternates between (2476 and 3688 v approximately equal) and 2476 v

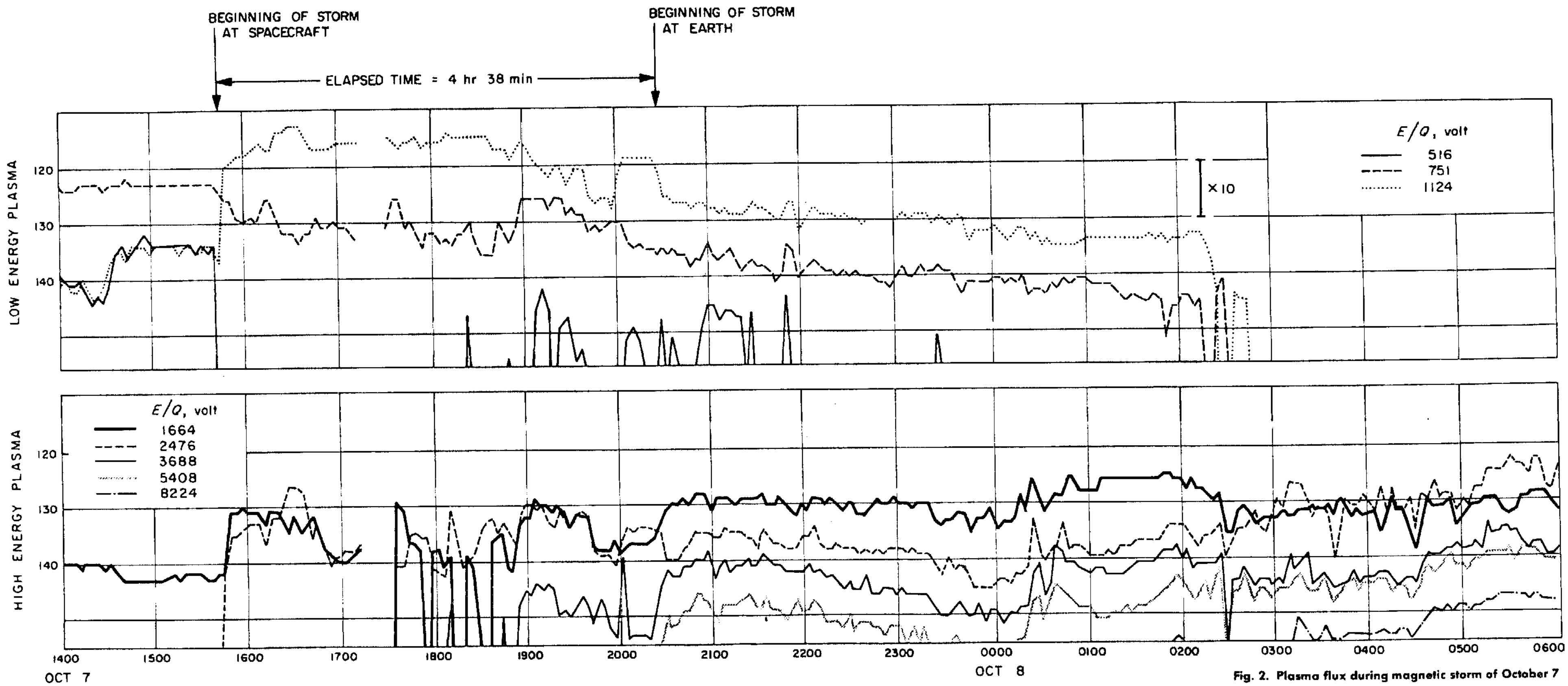

Fig. 2. Plasma flux during magnetic storm of October 7

III. SELECTED SPECTRA AND PRELIMINARY CONCLUSIONS

A few selected spectra are given in Fig. 3. An outstanding feature of many of the spectra is the presence of two peaks with the lower-voltage peak being the higher of the two. Because of the relatively wide spacing of values of E/Q for which the flux was measured, it is not possible to prove whether or not two peaks were always present. It is believed that the most probable explanation for the presence of two peaks is that the lower-voltage maximum is due to protons while the higher-voltage maximum is due to alpha particles with approximately the same bulk velocity as the protons (and thus twice the value of E/Q).

Another consequence of the wide spacing of values of E/Q is the difficulty in determining the density and temperature of the plasma. Estimates have been made for only a few spectra so far. The values for the spectra in Fig. 3a and 3f were estimated based on a model in which the plasma flows directly from the Sun with a bulk velocity v_0, density n, a proton temperature T in the direction of motion, and zero proton temperature perpendicular to the direction of motion, with the following results:

Spectrum 3a	*Spectrum 3f*
$v_0 = 460$ km/sec	$v_0 = 810$ km/sec
$n = 2.5$ cm^{-3}	$n = 4.5$ cm^{-3}
$T = 1.9 \times 10^5$ °K	$T = 7.4 \times 10^5$ °K

These figures were based on the further assumption that the currents at the three lowest values of E/Q were due to protons only.

Another model which we hope soon to be able to compute has equal proton temperatures parallel and perpendicular to the direction of motion. In this respect, it should be noted that the plasma flow observed by *Explorer X* was estimated to have ion temperatures of the order of 10^5 and 10^6 °K perpendicular and parallel to the bulk velocity, respectively (Ref. 3).

If we assume that the values of v_0, n, and T given above are approximately correct, and further assume an average value for the interplanetary magnetic field of $B = 5$ gamma $= 5 \times 10^{-5}$ gauss, we can compute the following important parameters for spectrum 3a, which are fairly representative of quiet, non-storm conditions in interplanetary space:

$$\text{Plasma flux} = n\, v_0 = 1.2 \times 10^8 \text{ cm}^{-2}\text{sec}^{-1}.$$

$$\text{Plasma energy density} = n\left(\frac{1}{2} m v_0^2 + \frac{1}{2} kT\right)$$

$$\approx \frac{1}{2} n m v_0^2 = 4.4 \times 10^{-9} \text{ ergs cm}^{-3}.$$

$$\text{Magnetic field energy density} = B^2/8\pi = 1.0 \times 10^{-10} \text{ ergs cm}^{-3}.$$

$$\text{Alfvén velocity} = v_A = B/\sqrt{4\pi m n} = 69 \text{ km sec}^{-1}.$$

$$v_0/v_A = 6.7.$$

The following conclusions can be made from these computations:

1. The plasma flux is in good agreement with the values found by *Explorer X* (Ref. 3) and by the ion traps on the *Luniks* (Ref. 4).

2. The plasma velocity, v_0, however, appears to be about 50% greater than that observed close to the Earth by *Explorer X*. In general, the difference is even greater because spectrum 3a has a somewhat lower than average value of v_0, as can be seen from Table 1. The measured velocity agrees fairly well with the value predicted from Parker's "solar wind" theory (Ref. 5 and 6), but it is much higher than the values predicted by "solar breeze" theories (Ref. 7 and 8) and from the observation of comet-tail orientations (Ref. 9).

3. The plasma energy density is greater than the energy density of the magnetic field by a factor of 44. Thus we may conclude that the magnetic field in interplanetary space is carried along by the plasma with the field giving little or no hindrance to the plasma flow.

4. The flow of plasma about the Earth and its magnetosphere is supersonic in the sense that the flow velocity is greater than the Alfvén velocity, probably a necessary condition to produce the predicted bow shock wave (Ref. 10 and 11).

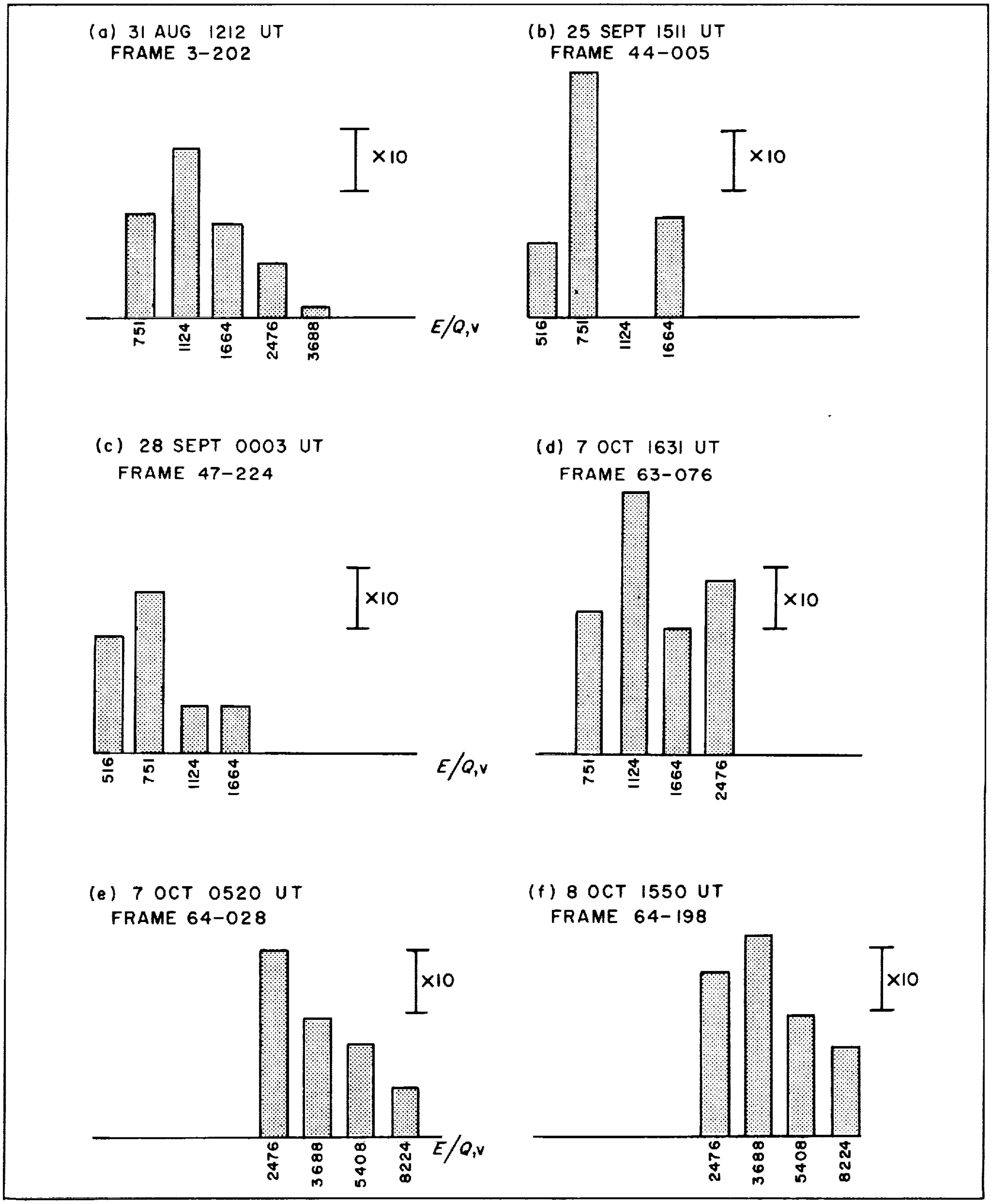

Fig. 3. Selected plasma spectra

REFERENCES

1. "Scientific Experiments for Mariner R-1 and R-2," Technical Report No. 32-315, Jet Propulsion Laboratory, July 15, 1962.

2. Jet Propulsion Laboratory Space Program Summary, No. 37-14, p. 14, Jet Propulsion Laboratory, Pasadena, April 1, 1962.

3. Bonetti, A., H. S. Bridge, A. J. Lazarus, E. F. Lyon, B. Rossi, and F. Scherb, "Explorer X Plasma Measurements," paper presented at COSPAR meeting, Washington, D.C., May, 1962.

4. Gringauz, K. I., V. V. Bezrukikh, V. D. Ozerov, and R. E. Rybchinskii, "A Study of the Interplanetary Ionized Gas, High-energy Electrons, and Corpuscular Radiation from the Sun by means of the Three-electrode Trap for Charged Particles on the Second Soviet Cosmic Rocket," *Soviet Physics, Doklady,* Vol. 5, p. 361, 1960.

5. Parker, E. N., "The Hydrodynamic Treatment of the Expanding Solar Corona," *Astrophysical Journal,* Vol. 132, pp. 175-183, 1960.

6. Parker, E. N., "The Hydrodynamic Theory of Solar Corpuscular Radiation and Stellar Winds," *Astrophysical Journal,* Vol. 132, pp. 832-866, 1960.

7. Chamberlain, J. W., "Interplanetary Gas. II. Expansion of a Model Solar Corona," *Astrophysical Journal,* Vol. 131, pp. 47-56, 1960.

8. Chamberlain, J. W., "Interplanetary Gas. III. A Hydrodynamic Model of the Corona," *Astrophysical Journal,* Vol. 133, pp. 675-687, 1961.

9. Brandt, J. C., "A Model of the Interplanetary Medium," *Icarus,* Vol. 1, pp. 1-6, 1962.

10. Axford, W. I., "The Interaction between the Solar Wind and the Earth's Magnetosphere," *Journal of Geophysical Research,* Vol. 67, pp. 3791-3796, 1962.

11. Kellogg, P. J., "Flow of Plasma around the Earth," *Journal of Geophysical Research,* Vol. 67, pp. 3805-3811, 1962.